SHORT-TERM CONTROLLED ATMOSPHERE STORAGE FOR SHELF-LIFE EXTENSION OF APRICOTS[1]

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ABSTRACT

Shelf-life of 'Perfection' and 'Rival' apricots can be enhanced with the use of controlled atmosphere (CA) storage. Apricots were harvested at commercial maturity and immediately stored in CA at 1 or 2% O_2 and 3, 6, 9, 12 or 15% CO_2 for 30, 45 and 60 days. No differences in fruit quality were evident between O_2 atmospheres of 1 and 2%, except that fruit stored in 1% O_2 displayed less rot development and higher acid content. Apricots stored in 9% or less CO_2 displayed reduced external and internal color, inadequate finish, increased internal breakdown and more rot development with unacceptable firmness retention for additional handling. Apricots stored in 12 or 15% CO_2 retained firmness and displayed enhanced finish with reduced rots and very little internal breakdown with storage duration of 60 days. Color was much slower to develop in apricots stored in 12 or 15% CO_2 for all storage periods.

INTRODUCTION

Apricot production is on the rise in Washington State with 560 ha presently in production (WASS 1993). As volume has increased, orderly marketing of the apricot crop has become an issue. The storage-life of apricots in regular atmosphere (RA) storage is relatively short (Claypool and Pangborn 1972). An

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extension of 30 to 60 days of the shelf-life of apricots would improve the marketing of this crop. CA storage has been suggested as a way to enhance the shelf-life of apricots and thus extend the marketing time. Presently in Washington State there are numerous controlled atmosphere (CA) storage facilities that are under-utilized during the months of July and August, the same time period when most apricots in WA are harvested and stored.

Use of CA to extend the shelf-life of fruits is a common procedure and its use is increasing. CA storage of apricots with varied results has been reported. Wankier *et al.* (1970) demonstrated that CA storage of apricots with an optimal CO_2 of 2.5% aids in the retention of firmness, titratable acidity and total sugars. Increasing CO_2 above 2.5% accelerated accumulation of succinic acid and the depletion of malic acid. Claypool and Pangborn (1972) stated that canned apricots had a better flavor when stored in air (RA) rather than CA prior to canning, but rate of flavor and acidity loss was less in CA stored apricots. Little *et al.* (1989) suggested that the best atmosphere for the CA storage of apricots was low O_2 and high CO_2. Kader (1989) reported that an atmosphere of 2% O_2 and 3% CO_2 was best for apricots with possible injury to the fruit at CO_2 concentrations >5%, depending upon the cultivar and storage duration. Tonini *et al.* (1989) found that nectarines could be stored for 40 days with good results at 0C in 1.5 to 2.0% O_2 and 9 to 10% CO_2. Charmbray *et al.* (1991) found that high levels of CO_2 (1.0 to 30%) used as a pretreatment prior to storage in air reduced firmness loss and incidence of brown rot. In addition, apricots stored in 5% CO_2 displayed reduced respiration rate and firmness loss. Kaji *et al.* (1991) reported that high CO_2 (3 to 13%) delayed color development and reduced injury of apricots during CA storage periods of 23 days. Streif *et al.* (1992) found a high CO_2 concentration (20%) delayed ripening of nectarines, kept fruit firmer, prevented the development of internal browning and produced fruit with high sensory scores with no off-flavors. Lurie (1992) found that 3 cultivars of nectarines stored well for up to 6 weeks at 0C in 10% O_2 and 10% CO_2 with no internal breakdown, but CA storage also prevented development of juiciness after storage. Ben-Arie *et al.* (1993) reported that CA storage of nectarines under high CO_2 reduced internal breakdown and the severity of color change. This study was initiated to determine the feasibility of using CA storage to lengthen the shelf-life of 'Perfection' and 'Rival' apricots.

MATERIALS AND METHODS

This study was conducted over 3 crop seasons using 'Perfection' and 'Rival' apricots (*Prunus armeniaca*). Each season apricots were harvested 1 day prior to commercial harvest from commercial blocks located close to Quincy, WA. The same blocks were used for all years of the study. Nine hundred apricots of uniform size and color were harvested, 300 from each of 3 locations within the orchard for both cultivars. Immediately after harvest, the apricots were placed in either regular atmosphere (RA) or controlled atmosphere (CA) storage at 1C. Atmospheres in the CA chambers (~ $0.14M^3$) were 1 and 2% O_2 and 3, 6, 9, 12 and 15% CO_2 the first year and 1% O_2 with the same CO_2 atmospheres the following years. Atmospheres were established in less than 12 h and maintained at ± 0.1% using a computer control system (Technical Consulting Services, Chelan, WA). Nitrogen was supplied by a membrane separation system and CO_2 was injected when required to meet prescribed levels.

After 30, 45 or 60 days of storage the apricots were removed for quality evaluation. Thirty apricots from each cultivar, atmosphere and replication were used for quality analysis after each storage period. Fifteen apricots from each cultivar and treatment combination were examined immediately upon removal from storage. An additional 15 apricots from each cultivar and treatment combination were examined for quality after 15 days in RA or after 2 or 7 days of ripening at 20C. A factorial design was used for data analysis using atmospheres as the main plots with storage and ripening as the subplots. Analysis of variance was determined by MSAT-C (1988) and means were separated using Tukey's test.

Quality factors evaluated were firmness, external and internal color, solids concentrations (SSC) titratable acidity (TA) and visual disorders (rots, finish and internal breakdown). Firmness was determined by the TA-XT2 Texture Analyzer (Scarsdale, NY) equipped with a 7.8 mm probe and reported as Newtons (N). External and internal color was determined with The Color Machine (Pacific Scientific, Silver Springs, MD) using the Hunter L*, a*, b* system and calculated Hue (h°) values (Hunter and Harold 1987). Two values for external color were determined at equal distance around the circumference of the apricot. Internal color was measured by cutting each apricot in half vertically and immediately reading the exposed flesh surface. The average of 15 apricots was reported for color analysis. SSC of the extracted juice was determined with an Abbe type refractometer calibrated at 20C. TA was determined using the Radiometer Titrator Model TTT 85 (Radiometer, Copenhagen). Juice extracted from the apricots was titrated to pH 8.2 with 0.1 N NaOH and values expressed as percent malic acid. Visual observations for rots and internal breakdown were conducted by the same laboratory personnel (1) during the entire study. Rot was evaluated as present or absent and reported in percent affected. Finish was visually graded on a scale of 1 to 4 where 1=excellent, 2=good, 3=fair and 4=poor. Internal breakdown was evaluated as two groups, acceptable=slight or none and unacceptable=moderate or severe visible breakdown and reported as percent affected.

RESULTS AND DISCUSSION

During the first year of this study it was determined that an O_2 level of either 1 or 2% had little influence on 'Perfection' fruit quality, except for external h°, TA and percent rots (Table 1). Differences in h° between the two O_2 levels was <1 unit and was judged not to be of major consideration. Differences in TA and rots between the two O_2 levels were considered significant. Fruit held in a 1% O_2 atmosphere for 45 days had a higher TA and less visible percentage of rot (40%) than fruit stored in 2%. Carbon dioxide level in the storage atmosphere had a major influence on the external and internal color, internal breakdown, firmness and TA present in fruit after storage. As the CO_2 level was increased from 3 to 15%, Hunter L* values increased (lighter color), but after 2 days of storage at ambient temperature fruit L* values declined, except for fruit exposed to 12 or 15% CO_2 where the L* values remained the same. External h° (orange) values did not change as a result of ambient temperature storage. Internal L* values were much darker (lower) for fruit held in 3, 6, or 9% CO_2 when compared to fruit held in 12 or 15%, particularly after 2 days of ambient temperature storage. Internal L* values did not change appreciably for fruit held at 12 or 15% CO_2 during ambient temperature storage. There was a strong relationship between internal L* values and internal breakdown, as L* values decreased more internal breakdown was visible present. Internal breakdown of fruit was directly related to the amount of CO_2 in the storage atmosphere. As CO_2 increased, the amount of internal breakdown was reduced. Fruit exposed to 9 to 15% CO_2 displayed little internal breakdown (<3%); whereas, fruit exposed to 3 to 6% displayed high (>39%) internal breakdown. After 2 days of storage at ambient temperature this difference in CO_2 related internal breakdown was even more pronounced. Fruit exposed to 15% CO_2 displayed only 7% internal breakdown while fruit held in 12% CO_2 displayed 24% breakdown and fruit exposed to less to 9% or less CO_2 had major (50%) internal breakdown present.

Fruit firmness was strongly influenced by CO_2 content in the storage atmosphere (Table 1). As CO_2 increased, firmness was increased for the fruit held in a 6, 9, 12, or 15% CO_2 atmosphere with very distinct firmness retention for fruit held in 12 or 15%. After 2 days storage, at ambient temperature, firmness was similar regardless of CO_2 storage level and all fruit ripened to similar texture levels. SSC was not influenced by storage atmosphere or ambient temperature storage.

TA levels were similar in relation to CO_2 in the storage environment except after ambient temperature storage. Fruit stored in 12 or 15% CO_2 did not lose TA content during ambient temperature storage to the extent that fruit exposed to 3% lost TA. Fruit stored at 6, 9, and 12% CO_2 also lost TA, but were intermediate in loss between 3 and 15%. After this portion of the study was

TABLE 1.
QUALITY OF 'PERFECTION' APRICOTS AFTER 45 DAYS OF STORAGE AS INFLUENCED BY STORAGE ATMOSPHERE AND AMBIENT TEMPERATURE RIPENING

Treatments		Hunter Color External L*	Hunter Color External h°	Hunter Color Internal L*	Hunter Color Internal h°	Internal breakdown (%)[z] acceptable	Internal breakdown (%)[z] unacceptable	Firm (N)	Titratable Acidity (%malic)	Finish (1 to 4)[z]	Rots (%)
O_2, 1 %		50.0a[x]	82.3b	51.0a	69.3a	69a	31a	29.7a	1.92a	2.1a	6.6b
O_2, 2 %		49.4a	83.2a	52.4a	69.0a	68a	32a	29.8a	1.85b	2.0a	11.0a
CO_2% x Ripe (days)											
3	0	47.2ef	81.5b	51.4ab	68.1a	50cd	50bc	21.9c	1.99b	2.3d	10bc
	2	44.5g	86.7a	43.7c	69.6a	21e	79a	19.4	1.61d	3.8a	39a
6	0	48.4de	82.8b	51.6ab	69.4a	61bc	39c	37.0b	2.09ab	2.1d	4.0cd
	2	45.3fg	87.5a	45.4c	70.0a	38d	62b	22.2de	1.65cd	3.5b	17b
9	0	50.1cd	79.8b	52.8ab	66.3a	97a	3e	39.2ab	2.15a	1.5e	3cd
	2	48.6de	86.1b	49.0bc	70.3a	51cd	49bc	23.7d	1.71cd	2.6c	5cd
12	0	51.7bc	79.2b	56.2a	69.5a	100a	0e	41.9a	2.08ab	1.0g	1d
	2	53.5ab	82.1b	55.1a	69.6a	76b	24d	21.0de	1.75c	1.3f	6cd
15	0	53.1ab	79.9b	55.4a	69.8a	100a	0e	41.9a	2.08ab	1.0g	2cd
	2	54.7a	81.8b	56.7a	68.9a	93a	7e	19.5	1.75c	1.0g	2cd

[z]Percent visual internal breakdown graded on a scale of acceptable or unacceptable.
[y]Graded on a scale of 1 to 4; where 1=excellent, 2=good, 3=fair and 4=poor.
[x]Means in a column, within treatments, not followed by a common letter are significantly different by ANOV or THSDT ($P \leq 0.05$.

completed, it was determined that an atmosphere of only 3% CO_2 would not be sufficient to maintain fruit quality due to loss of color, finish and greatly increased internal breakdown. This atmosphere (2% O_2) was not repeated in subsequent years.

Quality of 'Perfection' apricots stored in CA for 45 days and 15 days in RA was directly related to the CO_2 in the CA storage atmosphere (Table 2). Fruit held in RA for 60 days did not display a change in L* color values. Fruit stored 45 days in 6, 9, 12, or 15% CO_2 and then placed in RA for 15 days lost color or became darker (lower L*). Immediately after the 45 days storage period fruit exposed to 15% CO_2 were similar in L* values to fruit stored in RA for 45 days. However, after the addition of RA storage for 15 days, fruit exposed to 15% CO_2 were darker (lower L*) than RA fruit stored for a similar 60 days. Fruit stored in 6 and 9% CO_2 were very dark in color at the end of 60 days and were deemed unacceptable by laboratory personnel. Fruit stored at 12 and 15% CO_2 had a more acceptable color and were not as dark as fruit exposed to 6 or 9%.

TABLE 2.
QUALITY OF 'PERFECTION' APRICOTS AFTER 45 DAYS OF STORAGE AS INFLUENCED BY STORAGE ATMOSPHERE AND 15 DAYS ADDITIONAL STORAGE IN REGULAR ATMOSPHERE @ 1C

Treatments		External L*	Hunter Color Internal L*	Internal h°	Firm (N)	TA (%malic)
Atmosphere						
(RA)		56.2a[z]	52.6a	70.3b	8.9c	1.49c
6% CO_2		43.9d	43.0c	79.4a	37.4b	1.72b
9%		45.6cd	44.7c	81.8a	39.9ab	1.78ab
12%		49.5bc	47.9b	79.0a	44.7a	1.86ab
15%		52.4ab	51.5a	79.8a	45.6a	1.93a
Atmosphere x	**Ripe (days)**					
RA	0	57.3a	54.1abc	72.0bc	11.3g	1.56de
	15	55.2ab	51.1cde	68.5c	6.5g	1.43e
6% CO_2	0	46.1e	44.9f	84.1ab	40.4def	1.92b
	15	41.8f	41.1g	74.7abc	35.4f	1.53e
9%	0	49.1cd	48.2ef	86.8a	44.0cd	2.00ab
	15	42.0f	41.2g	76.9abc	35.8ef	1.55de
12%	0	53.9b	49.8de	78.6abc	47.3bc	2.04cb
	15	45.2e	46.1f	79.5abc	42.1cde	1.68cd
15%	0	57.6a	54.9ab	84.2ab	52.0ab	2.154a
	15	47.2de	48.1ef	75.4abc	39.3def	1.71c

[z]Means in a column, within treatments, not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

Internal color (L* and h°) was also related to the concentration of CO_2 in the storage environment. Fruit stored in 15% CO_2 for 45 days were similar in color to fruit stored 60 days in RA alone. Fruit stored in different levels of CO_2 darkened (lower L*) during 15 days in RA storage. Fruit stored in RA for the entire storage period did not darken, but became lighter (higher L*) in color. Fruit stored in 6% CO_2 were much darker in internal color than fruit stored in 9, 12, or 15% after 45 days. This difference in color between fruit from the various CO_2 storage levels became much more pronounced after 15 days of RA. Fruit exposed to 6 and 9% CO_2 were darker than fruit exposed to 12 and 15%. Internal h° for fruit was the same regardless whether fruit were held in RA or CA storage. An additional 15 days did not change the differences in h° or orange color between fruit from RA or CA. Fruit held in RA alone tended to darken more rapidly than fruit held in CA then RA. Internal color was minimally acceptable only for fruit stored in 12 and 15% CO_2.

Firmness of fruit held in RA for 45 days was much less than the firmness of fruit held at various levels of CO_2. Fifteen days of additional storage of fruit from both types of atmospheres (CA or RA) showed a similar firmness pattern. Fruit firmness loss during this 15 day period was much slower than in fruit originally held in only CA. CO_2 in the storage environment also helped to maintain TA levels in stored fruit. After 15 days in RA, the TA levels were similar for all fruit except those fruit stored in 12 or 15% CO_2 for 45 days prior to the 15 days in RA.

Firmness of 'Perfection' apricots, after 30 days of CA and 7 days of ripening was similar regardless of CO_2 level in the storage atmosphere (Table 3). CA stored fruit was firm enough to where handling would not result in adverse quality due to bruising. RA stored fruit, after 30 days, were very soft in texture (14 N) and were soft enough that handling would reduce quality. Fruit from both types of storage (RA and CA) ripened to the same firmness level after 7 days at ambient temperature storage.

CA storage of fruit in CA at 6, 9, 12 and 15% CO_2 had no influence on the external L* values (Table 3). Fruit stored in RA for the same time period had high L* values, or lighter color than fruits from CA storage. After 7 days at ambient temperature, L* values for fruit from RA were much less than L* values for fruit from CA. Little difference in external h° (orange color) was observed for fruit regardless of storage type or duration of storage. No internal color differences developed during RA or CA storage of 30 days followed by 7 days at ambient temperature. Immediately after 30 days of storage, there were differences in TA. Fruit from CA had higher TA values than fruit from RA. But after an additional 7 days of ambient temperature storage, TA values were the same regardless of storage type.

TABLE 3.
QUALITY OF 'PERFECTION' APRICOTS AFTER 30 DAYS OF STORAGE AS INFLUENCED BY STORAGE ATMOSPHERE AND DAYS AT AMBIENT TEMPERATURE RIPENING

Treatment		Firm (N)	External Hunter Color L*	h°	TA (%malic)
Atmosphere x	**Ripe (days)**				
RA	0	14.0b[z]	53.8a	73.9a	1.36bc
	7	2.5c	49.0c	65.5ab	1.26c
6% CO_2	0	26.8a	52.0b	76.1a	1.78b
	7	4.2c	52.4ab	66.0ab	1.30ab
9%	0	28.5a	51.5b	55.0b	1.78b
	7	4.2c	52.1b	64.3ab	1.27c
12%	0	17.3ab	51.6b	74.1a	1.50b
	7	3.7c	52.3b	66.1ab	1.28c
15%	0	22.7a	52.8b	66.2ab	1.69b
	7	4.6c	51.9b	65.3ab	1.24c

[z]Means in a column not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

There is no doubt that increased CO_2 in the storage atmosphere aided in firmness retention for both 'Perfection' and 'Rival' apricots (Table 4 and 5). When compared to the firmness of fruit after 60 days in RA or after 2 days at ambient temperature, apricots stored in CA with elevated CO_2 (6 to 15%) were much firmer. Firmer fruit generally did not display objectional bruising. 'Perfection' apricots (Table 4) stored in an elevated CO_2 atmosphere were very firm when removed from storage. 'Perfection' apricots stored in 6% CO_2 did not lose firmness as rapidly as fruit stored in 9, 12 or 15%. 'Rival' apricots (Table 5) reacted similarly to 'Perfection' apricots when those fruit stored in elevated CO_2 remained firmer than apricots stored in RA. 'Rival' apricots stored in 6 or 9% CO_2 lost firmness more rapidly than fruit stored in 12 or 15%.

'Perfection' and 'Rival' apricots stored in 6% CO_2 had a darker external color (lower L*) than either fruit from RA or fruit stored in 9, 12, or 15% CO_2. This color difference for fruit stored in 6% was also true for the h° (orange) of 'Rival' apricots, which would indicate a darker orange color of fruit stored in this manner. As CO_2 content in the storage atmosphere was increased from 6 to 15%, L* values increased for both cultivars of apricots. Hue also increased for 'Rival' apricots as CO_2 in the storage environment increased. Ripening of fruit for 2 days produced darker fruit with lower L* and h°, for fruit stored in 6, 9, 12% CO_2. After ripening, external color remained the same, for fruit from RA

TABLE 4.
QUALITY OF 'PERFECTION' APRICOTS AFTER 60 DAYS OF CONTROLLED ATMOSPHERE STORAGE AS INFLUENCED BY STORAGE ATMOSPHERE AND DAYS AT AMBIENT TEMPERATURE RIPENING

Treatments		Firm (N)	Titratable acidity (%malic)	Hunter Color External L*	Hunter Color External h°	Hunter Color Internal L*	Hunter Color Internal h°	Rots (%)	Finish (1 to 4)[z]	Internal Breakdown (%)[y] acceptable	Internal Breakdown (%)[y] unacceptable
Atmosphere											
RA		8.5b[x]	1.63b	63.1ab	60.5b	45.2bc	52.2b	22.5a	1.2c	85b	15b
6% CO_2		39.5a	1.98a	58.7d	71.8a	44.3c	54.7a	17.2b	1.8a	71c	29a
9%		36.3a	1.98a	60.1c	71.1a	45.9b	54.8a	10.4c	1.6b	84b	16b
12%		36.9a	2.05a	62.2b	71.8a	47.6a	56.0a	3.1d	1.1c	95a	5c
15%		34.8a	1.99a	63.9a	70.5a	48.5a	55.3a	1.5d	1.1c	94a	6c
Atmosphere x Ripe (days)											
RA	0	10.4d	1.55e	62.5c	60.7d	47.5c	52.5cd	6.6c	1.1de	98a	2c
	2	6.4d	1.71de	63.7b	60.2d	42.9e	52.0d	38.5a	1.3c	72b	27b
6% CO_2	0	44.2a	2.08ab	59.6e	73.8a	47.5c	56.1ab	1.1c	1.2d	100a	0c
	2	34.8b	1.89bcd	57.7f	69.9b	41.1f	53.3cd	33.2a	2.5a	42c	58a
9%	0	43.0a	2.12a	60.8d	73.8a	48.8b	56.0ab	0.5c	1.0e	100a	0c
	2	29.6bc	1.85cd	59.5e	68.4bc	43.0e	53.6cd	20.4b	2.3b	65b	35b
12%	0	45.4a	2.12a	62.1c	76.4a	50.2a	57.7a	0.0c	1.0e	98a	2c
	2	28.3c	1.97abc	62.3c	67.2bc	45.1d	54.3bc	6.1c	1.3c	92a	8c
15%	0	45.2a	2.07ab	62.4c	75.0a	49.9ab	56.1ab	0.0c	1.0e	97a	3c
	2	24.3c	1.91bc	65.3a	66.0c	47.1c	54.4bc	3.0c	1.2d	92a	8c

[z]Graded on a scale of 1 to 4; where 1=excellent, 2=good, 3=fair, and 4=poor.
[y]Percent visual internal breakdown graded on a scale of acceptable or unacceptable.
[x]Means in a column, within treatments, not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

TABLE 5.

QUALITY OF 'RIVAL' APRICOTS AFTER 60 DAYS OF CONTROLLED ATMOSPHERE STORAGE AS INFLUENCED BY STORAGE ATMOSPHERE AND DAYS AT AMBIENT TEMPERATURE RIPENING

Treatments		Firm (N)	Hunter Color External L*	External h°	Internal L*	Internal h°	Rots (%)	Finish (1 t0 4)[z]	Internal Breakdown (%)[y] acceptable	unacceptable
Atmosphere										
RA		15.9c	61.2a	47.4c	46.4a	48.6a	6.3b	1.0c	90a	10c
6% CO_2		18.4b	57.4d	52.0b	41.2d	40.6c	19.4a	1.8a	43c	57a
9%		24.0a	60.1b	56.4a	43.0c	43.0b	0.5c	1.5b	71b	29b
12%		25.8a	60.1b	53.6ab	44.2bc	43.7b	0.3c	1.0c	98a	2c
15%		25.1a	62.4a	54.6ab	44.6b	43.5b	0.3c	1.0c	98a	2c
Atmosphere x Ripe (days)										
RA	0	23.4b	60.7ab	47.9de	49.4a	51.0a	2.1c	1.0c	94a	6c
	2	8.3c	61.6ab	46.9e	43.4d	46.2b	10.5b	1.0c	86a	14c
6% CO_2	0	23.3b	58.2cd	52.3cd	44.7c	42.6bc	1.7c	1.0c	60b	40b
	2	13.7d	56.5d	51.8cd	37.7f	38.6d	37.2a	2.6a	27d	73a
9%	0	30.3a	60.7ab	59.9a	46.1bc	44.4cd	0.0c	1.0c	97a	3c
	2	17.7cd	59.5bc	53.1bc	39.8e	41.6bc	1.0c	2.0b	46c	54ab
12%	0	31.7a	61.5ab	56.5ab	46.5bc	44.2bc	0.3c	1.0c	100a	0c
	2	19.9bc	62.6a	50.6cde	41.9d	43.3bc	0.3c	1.1c	97a	3c
15%	0	30.9a	62.1a	58.4a	46.6b	43.7bc	0.0c	1.0c	100a	0c
	2	19.4bc	62.6a	50.9cde	42.6d	43.3bc	0.7c	1.1c	96a	4c

[z]Graded on a scale of 1 to 4; where 1=excellent, 2=good, 3=fair, and 4=poor.

[y]Percent visual internal breakdown graded on a scale of acceptable or unacceptable.

[x]Means in a column, within treatment, not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

except that the L* values for 'Perfection' apricots increased. External color of 'Perfection' apricots stored in 15% CO_2 and ripened for 2 days displayed increased L* and decreased h°; whereas, the L* values for 'Rival' apricots remained the same and h° decreased. The darker (lower L*) more orange color (decreased h°) for apricots stored in 6% CO_2 was particularly evident after 2 days of ripening.

A very dark internal color (lower L*) was noted for both cultivars of apricots stored in 6% CO_2. As CO_2 increased L* values increased for both cultivars. High L* values were present for 'Perfection' apricots stored in 12 or 15% CO_2 and these values far exceeded the L* values for fruit from RA or fruit stored in 6 or 9% CO_2. A similar trend in increased L* values for 'Rival' apricots stored in 15% CO_2 was present, but the L* values for 'Rival' apricots stored in elevated CO_2 never reached the same value as apricots stored in RA. 'Perfection' apricots stored in elevated CO_2 had similar h° regardless of the amount of CO_2 and were less orange than apricots from RA storage. 'Rival' apricots stored in 6% CO_2 were very dark orange in color. As CO_2 was increased 'Rival' apricots displayed a less orange color but were not comparable to the color (h°) of fruit from RA storage, which displayed a higher h°, or less orange color. Two days of ripening resulted in a darker color for both cultivars of apricots. 'Perfection' apricots stored in 15% CO_2 after 2 days of ripening displayed L* values similar to apricots from RA prior to ripening. L* values for 'Rival' apricots after 2 days of ripening were similar for fruit from RA or 12 and 15% CO_2 storage. The internal L* values for apricots stored in 6 or 9% CO_2 after 2 days of ripening was very low (dark) and distinct for both cultivars. Orange color increased (lower h°) for both cultivars after ripening except for 'Perfection' apricots stored in 15% CO_2 and 'Rival' apricots stored in 12 or 15% CO_2. Internal color (h°) did not change during 2 days of ripening for both cultivars if stored in high CO_2 (12% or >).

The subjective scores for rots, finish and internal breakdown were highly dependent upon type of storage and agreed with objective values (firmness and color) for quality determination (Table 4 and 5). CO_2 storage inhibited the development of rots in both cultivars at 9% or above. Apricots stored in 6% CO_2 developed rots to a much greater extent than apricots in RA storage. Rot development increased during ripening, particularly in 'Perfection' apricots from RA or 6 and 9% CO_2 storage and for 'Rival' apricots from 6% CO_2 storage. 'Rival' apricots from RA storage did develop more rots during ripening, but not to the extent as fruit from 6% CO_2. 'Perfection' and 'Rival' apricots developed very little rot when stored in 12 or 15% CO_2 and after 2 days of ripening rot values were still similar.

Finish for both cultivars of apricots was related to external color and to some extent rot development. Apricots stored in 6 or 9% CO_2 were visually much darker in color than fruit from the other types of storage and determined to have an unacceptable finish (1.5 or >). Apricots from RA storage or from 12 or 15% CO_2 storage had similar finish scores and all had a bright acceptable (<1.5) apricot finish and color. Two days of ripening reduced scores for all apricots regardless of cultivar, except for 'Rival' apricots stored at 12 or 15% CO_2, where finish scores did not change during ripening. Finish scores for 'Perfection' apricots stored in 15% CO_2 were not reduced to the degree (1.2) that finish scores for apricots from other types of storage were reduced (1.3 or >).

High CO_2 storage (12 to 15%) inhibited the development of internal breakdown in both 'Perfection' and 'Rival' apricots. 'Perfection' apricots immediately after RA storage or 12 and 15% CO_2 storage displayed 3% or less internal breakdown. During ripening, internal breakdown of apricots from RA storage increased to 27%, which would be unacceptable; whereas, apricots stored in 12 or 15% CO_2 displayed only 8% internal breakdown. 'Perfection apricots' stored in 6 or 9% after 2 days of ripening displayed 58 to 35% respectively, unacceptable internal breakdown. 'Rival' apricots from RA storage or 12 and 15% CO_2 displayed very little internal breakdown (6% or <) immediately after storage. Furthermore, the level of internal breakdown did not increase significantly during ripening (14%). Apricots stored in 6% CO_2 had a very high percentage of internal breakdown immediately after storage (40%) and this breakdown increased to 73% after 2 days of ripening. 'Rival' apricots stored in 9% CO_2 had very little internal breakdown immediately after storage (3%), but after 2 days of ripening 54% of the apricots had unacceptable internal breakdown.

CONCLUSIONS

Researchers (Kader 1989; Claypool and Pangborn 1972; Wankier *et al.* 1970) have reported that high CO_2 storage of apricots is not recommended. Injury to apricots stored in high CO_2 was manifested by lack of flavor, increased internal breakdown and loss of acid content. Other reports (Little *et al.* 1989; Charmbray *et al.* 1991; Kaji *et al.* 1991) found that high CO_2 was beneficial for quality retention of apricots in storage. In this study it was determined that a low O_2 and high CO_2 (12 to 15%) enhanced quality retention in two cultivars of stored apricots. If the CA storage duration of apricots was 30 days or less, little quality differences was noted, regardless of the CO_2 concentration. However, a storage duration of 45 to 60 days resulted in reduced quality of apricots stored in 9% or less CO_2; whereas, quality of apricots stored in 12 to 15% CO_2 remained good. 'Perfection' and 'Rival' apricots stored at a concentration of 12 to 15% CO_2 retained firmness, displayed enhanced finish with reduced rots and had very little internal breakdown. Color was much slower to develop in apricots stored in 12 to 15% CO_2 and would possibly be a quality issue. Storage duration and the cultivar in question have a strong influence on quality of fruit held in CA storage. Both 'Perfection' and 'Rival' apricots can be stored in high CO_2 for shelf-life extension. Good fruit quality remains for storage periods up to 60 days. The best quality was observed for apricots stored for 45 days or less in high CO_2.

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